SPECTRUM BRIDGE

Observations and conclusions from experimental deployment of TV White Space networks

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Overview

Over the past 9 months Spectrum Bridge has designed and deployed several TV White Spaces trials and experiments. Each of these trials has employed frequency agile radios capable of operating in the VHF and UHF TV bands under the direction of a spectrum database. While the systems are deployed in accordance with FCC experimental licenses, we have made every effort to comply with the rules[1,2]. This report details the experiments performed and the results attained. While not exhaustive, we believe that the information gathered in the execution of these experiments provides useful information to help complete the TV White Spaces rule making process.

This report is organized into several sections. The first summarizes each trial network, its goals and outcomes. The next section describes decisions we made with respect to specific rules. The final section describes issues that occurred in attempting to comply with the rules on a practical basis. Practical experience yielded situations where the rules are unambiguous, but extremely difficult to comply with. We offer some suggestions on how the regulations may be enhanced to help improve the access to TV White Space, while improving the protection of incumbent operations.

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[1] Second Report And Order and Memorandum Opinion and Order, FCC 08-260, Adopted: November 4, 2008 http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-08-260A1.pdf

[2] Erratum for FCC 08-260, FCC DA-09-20, Released January 9, 2009 http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-08-260A1.doc

The Trial Networks

The Trial networks are all based on the High Power Fixed (4 Watt) definition described in the R&O. In each case, the radios were professionally installed and their location verified by portable GPS. This location was then configured within the radio. The stand-alone spectrum database and the software agent embedded in the radios were designed and developed by Spectrum Bridge. Third parties developed the radio hardware. The initial network design and deployment was carried out by Spectrum Bridge. In other cases, our partners deployed the networks. The solutions provide wide area outdoor coverage in point-to-point and point-to-multipoint configurations. The trial systems made use of multiple TV channels at a location but individual links are limited to TDD operation in a single 6MHz channel (no concatenation, channel bonding or FDD operation). Our goal was to evaluate TV White Spaces systems, components, performance and deployment models, not to determine the maximum throughput that could be achieved in a TV White Space channel. However, the throughput was typically considered 'broadband' and adequate for the applications deployed. Numerous technologies already exist that could increase the bits/Hertz and bits/Hertz/area beyond what we have currently deployed.

These trial systems have been running continuously and reliably for between 6 and 9 months. In each case, we provided information on the trial to the local Society of Broadcast Engineers and media. We have had no reports of interference with existing TV band users. In Wilmington, several High Power TV White Spaces radios are located on the premise of a TV and film production facility and no interference with existing operations has been detected.

The use of VHF and UHF frequencies has provided good propagation in Non Line Of Sight (NLOS) conditions. This capability has made the TV White Spaces radios ideal for outdoor deployments with ranges from 1-4 miles and moderate data throughputs (1-3 Mbps of sustained throughput in a single 6MHz channel). Even longer ranges could be achieved by relaxing the maximum antenna height restrictions on fixed TVWD transmitters, which would result in more efficient deployments and potentially higher broadband penetration in rural areas. Higher data rates could also be achieved by relaxing the TVBD transmit spectral mask, especially for fixed devices that are not allowed to operate on adjacent channels. Any interference risk could be mitigated by adjustments to the buffer zones in the database.

Because of the success of these trials and the value they are bringing to their local communities, Spectrum Bridge plans to upgrade these networks with FCC certified radios once the TV White Spaces rules are finalized.

Claudville Virginia

The first trial was deployed in a rural area of Virginia to provide broadband access to remote users. As this was the first TV White Spaces trial to be deployed, it was intentionally limited to a remote area and a small number of radios, all operating in the VHF band (Channels 7-13) (figure 1). This solution provided:

Internet access to a school,

Internet access to the local community via public WiFi hotspots,

Internet access to the local community using CPE

all within a 2 mile radius of an Internet Point Of Presence (POP)using White Spaces radios (figure 2).

Computers and software were donated by Dell and Microsoft. The broadband POP was provided through a grant from the Telecommunications Development Fund (TDF). As can be seen from the propagation model (figure 3), the use of White Space yielded significantly better coverage than a comparable 2.4GHz WiFi solution.

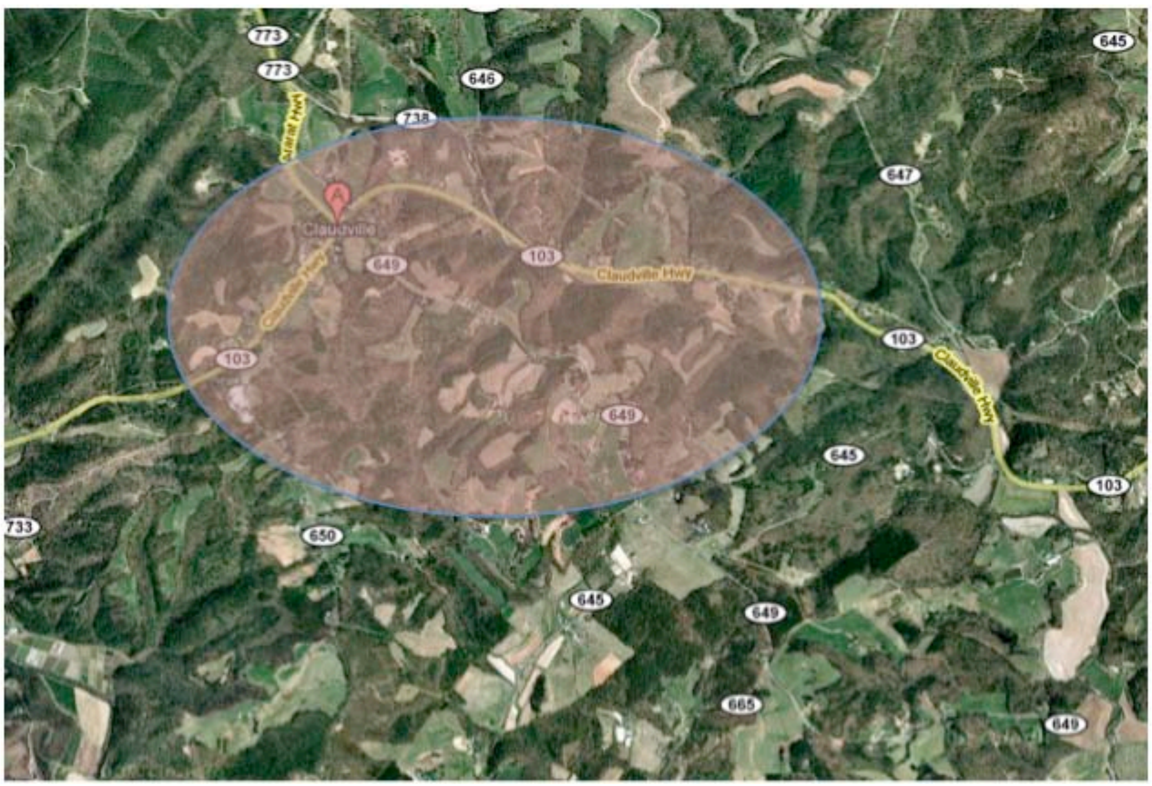

Figure 1: Claudville service area and location of Base station (A)

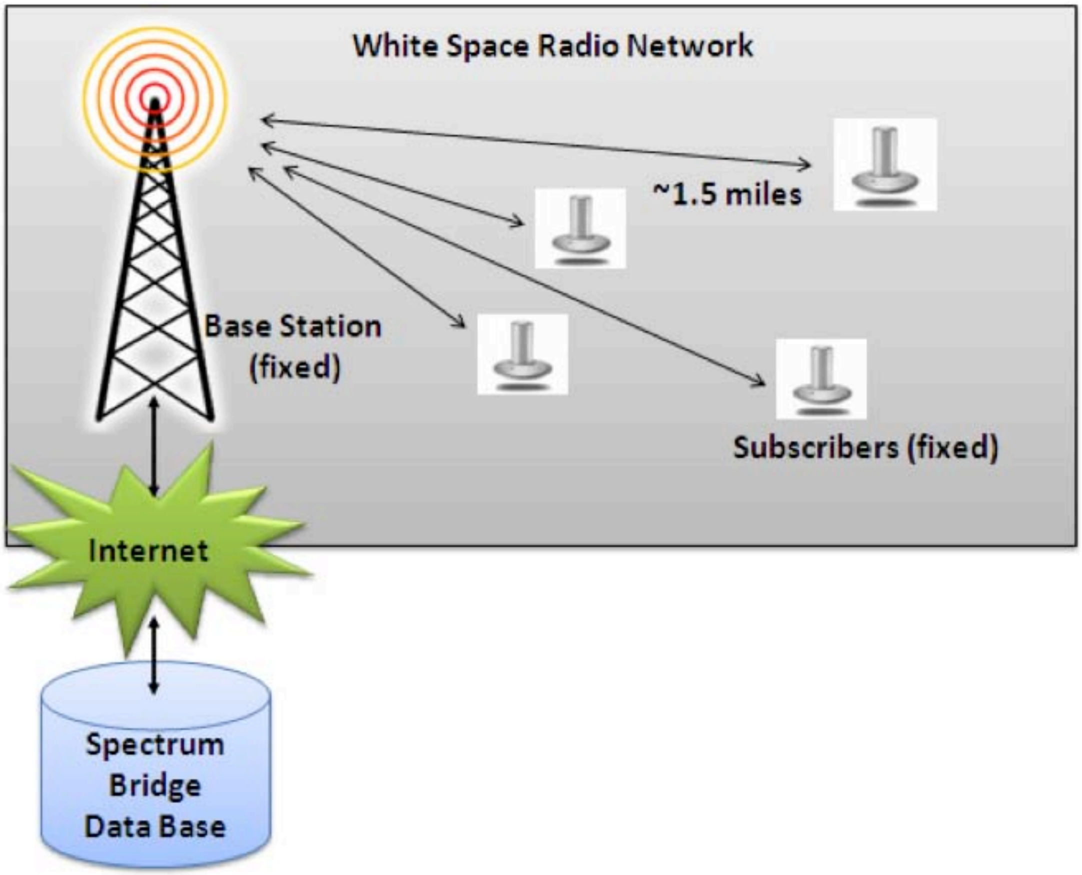

Figure 2: Network topology in Claudville

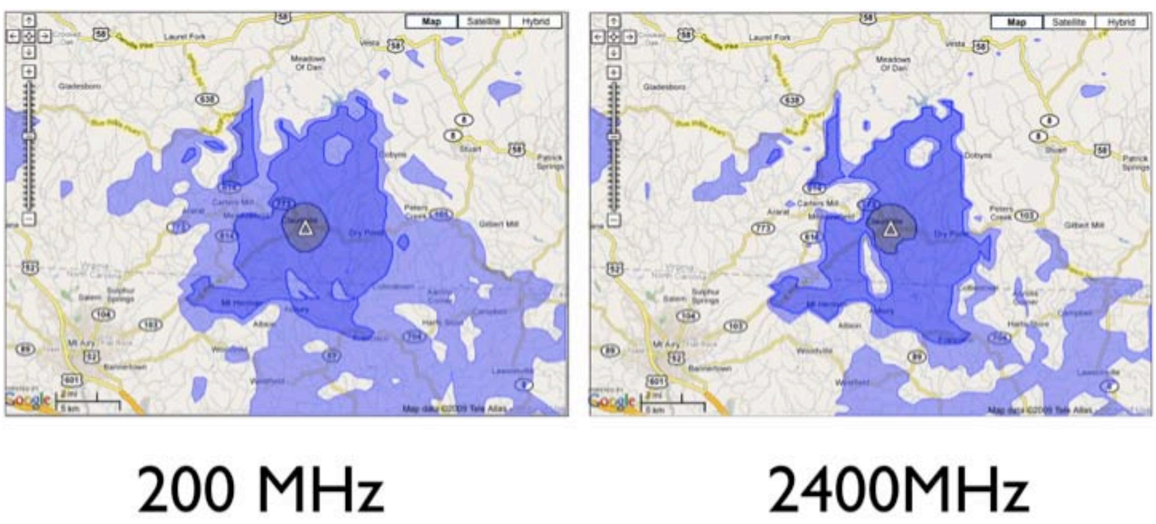

Figure 3:Comparison between propagation of VHF TV White Space frequencies and 2.4GHz ISM band

Wilmington North Carolina

The second trial was deployed in a more urban/suburban environment and includes a larger number of radios operating across the VHF and UHF bands. This trial, undertaken in partnership with TV Band Service, the city of Wilmington and the county of New Hanover, demonstrated “Smart City” applications. In addition to public WiFi, hot spots this deployment included public safety applications (remote cameras on evacuation routes), water level and water purity sensors for EPA, flood control and remote control of city facilities (lights in city parks). Several of the radios were deployed on the property of a TV and Film production facility in the city. The success of the trial has led the city and county to add new applications including remote monitoring and control of critical bridge and highway infrastructure.

Figure 4: Wilmington Service Area

The city of Wilmington is a very inter-connected city, from an Internet/network perspective. However, infrastructure still exists in outlying areas that had not been successfully attached to a network. TV White Space was ideal, because the cost of connecting these remote locations was made affordable by the inherent Non Line Of Sight (NLOS) performance advantages of VHF and UHF White spaces radios. In addition the TV White Spaces provided much needed spectrum that was not available to the city and county. While not a panacea, TV White Spaces provides a very useful means to complement the licensed wireless and wired options that the city has deployed.

Despite this success, the city and county governments do have some concern over using TV White Space for mission critical applications. They are now exploring the use of 700MHz public safety bandwidth in conjunction with UHF TV white space spectrum as complimentary solutions. We anticipate that the trials and experiments in Wilmington will be modified to evaluate some of these other options.

Plumas County California

The Network in Plumas County was deployed in partnership with the Plumas-Sierra Rural Electric Cooperative (PSREC). This innovative utility is looking to provide cost effective smart grid applications to rural and sparsely populated service areas. To date, there have been three components to the trial. The first was to provide monitoring and control of utility infrastructure. This includes broadband connectivity to several remote substations stations. The second was to provide remote monitoring and management of electricity use to their consumers. This was done in partnership with Google and included the deployment of TED (The Energy Detective) devices[3]. Finally several underserved and remote locations were provided broadband Internet access. In Plumas County, there is a significant amount of TV White Space available (~200MHz) and the utility can see the opportunity to leverage TV White Space in the roll out of its technology solutions, especially in geographically challenging areas. In some locations radio links are operating at close to 5 miles, which demonstrates the capability of TV White Spaces for last mile and middle mile solutions.

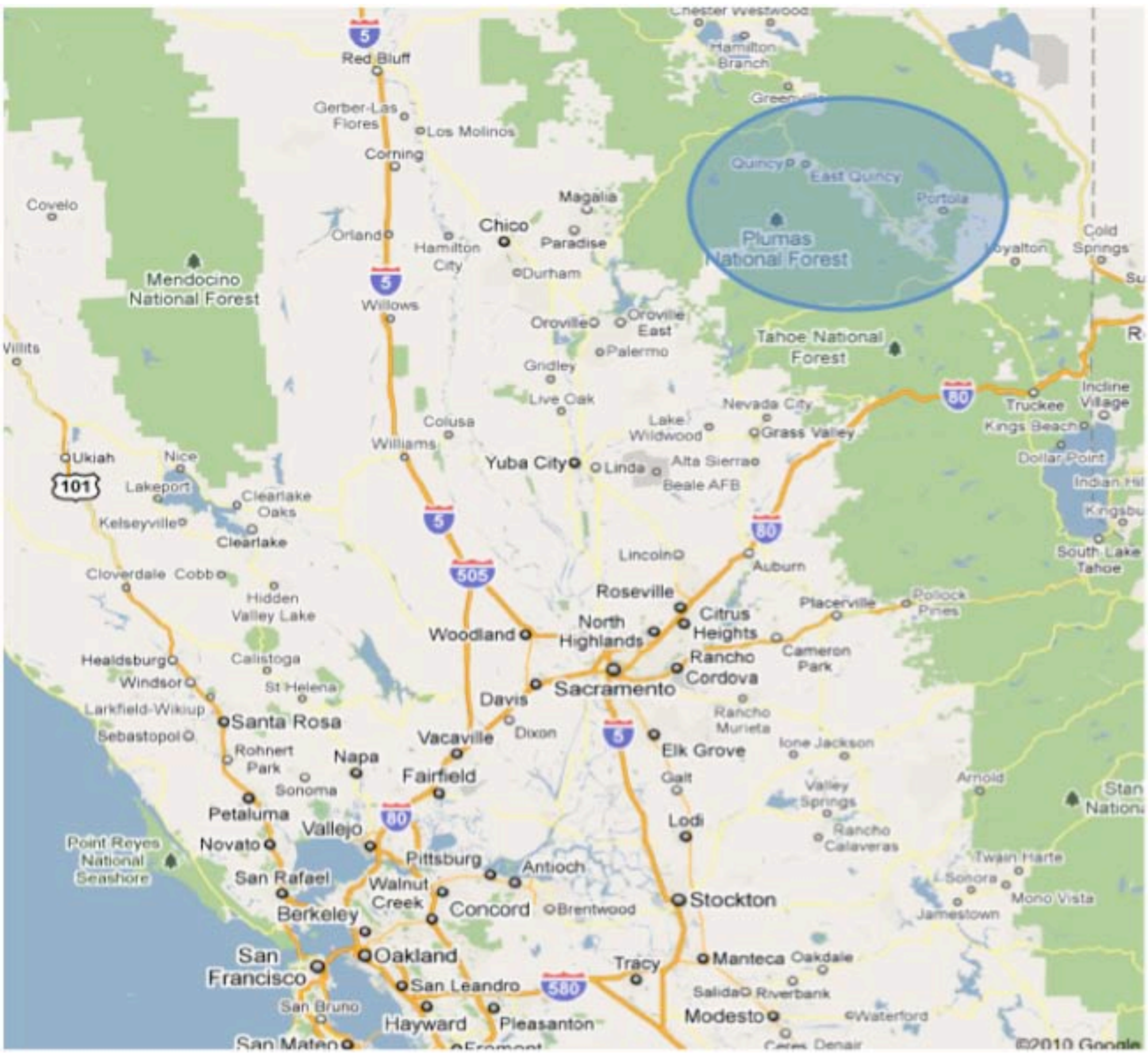

Figure 5: Location of the Plumas County Trial

[3] http://www.theenergydetective.com/about-ted

Lake Mary Florida

Spectrum Bridge has also installed a test network surrounding our facility in Lake Mary, FL to further develop and characterize white space radio technology and applications. In Lake Mary, we develop technology associated with the database and verify enhancements to the capabilities defined by the FCC. Some of these enhancements are described later in this document. We also develop device drivers for various radios (both vendor and technology). In addition we have been developing management and configuration applications that support the specific needs of White Spaces radios and their deployment. At this time we have prototypes of 802.11j based radios, proprietary FSK radios and 802.16e based radios with integrated white space database support. Because of the nature of the rules, all of these radios are more complex and costly than the technology requires, but it is reasonable to assume that they can be delivered at competitive pricing in volume, with one exception, - these radios cannot meet a sensing requirement. Given the results of our trials, the analysis and discussion of segmentation of TV White Spaces and the inherent cost (and questionable reliability) of sensing technology we strongly advise the FCC to remove the sensing requirement on TV band devices, provided the radios use a database solution as an alternative. Tests performed by Motorola show that legal spurious emission limits result in false sensing detections.

We have also made more complete measurements of the performance of the radios and the likelihood of interference in Lake Mary. We have found that the most significant interference to TV White Spaces devices is caused by TV transmitters. When observing the antenna height rule, a TV band device can detect interference from TV transmitters up to 200 miles away. Several channels that should be useable by TV band devices are rendered inoperable by the amount of energy received from these distant TV transmitters. Observations made by radio vendors have shown TV stations impacting +/- 3 adjacent channels. This phenomenon is described in detail below. We have not extensively measured the interference at ground level or indoors, though we do expect it to diminish significantly.

Interpretations made of FCC Rules

In this section we describe the way we addressed specific aspects of the rules as we designed and deployed the solutions.

Geographic Coordinates Stored in a Fixed TVBD

SBI assumes that geographic coordinates must be stored in the Fixed TVBD.

Registration of Fixed TVBDs

SBI assumes that a Fixed TVBD must register *itself* with the TV Bands database.

Registration of Personal/Portable TVBDs

SBI assumes that a Personal/Portable TVBD will not register with the TV Bands database.

FCC-Directed No Channels Available

SBI assumes that a TVBD will be notified when the FCC has directed that no channels are to be returned to one or more specific TVBDs.

Registration of Low Power Auxiliary Devices

SBI assumes that a both an owner name and contact name are required when registering a low power auxiliary device in the WSDB.

Translator Receive Site and Cable Headend Protection

SBI assumes the radius of the 60° segment for protection of translator receive sites and cable headends is a *maximum* of 80 km from the protected contour for co-channel operation and 20 km from the protected contour for adjacent channel operation.

If the associated TV station protected contour is closer than 80/20 km, the radius will be reduced to the distance to the protected contour.

TV Protected Contour

SBI currently utilizes the TV contour sets directly from the FCC's published contour data for the protected contours specified in 15.712(a)(1), instead of re-calculating the protected contours. We believe that this provides the most consistent approach to equivalent calculations from different databases. However our database is capable of both approaches.

The FCC published contours are generally accepted by the broadcast industry, so the practical approach is to simply use these contours. An alternative would be to adopt and use the algorithm the FCC uses to generate the contours as this would eliminate the need to independently derive systems to accomplish the same objective.

BAS Link Protection

SBI assumes the radius of the 60° segment for protection of BAS links is a *maximum* of 80 km from the transmitter for co-channel operation and 20 km from the transmitter for adjacent channel operation.

If the associated transmitter is closer than 80/20 km, the radius will be reduced to the distance to the transmitter.

Adjacent Channel Interference Protection

SBI assumes that adjacent channel interference protection rules apply only when a TV channel is adjacent in frequency, not simply adjacent by channel number. For this reason, the following channels are considered to have a single adjacent channel:

Channel	Low MHz	High MHz	Gap MHz	Adjacent Channel
2	54	60		3 only
3	60	66		
4	66	72		
gap	72	76	4	
5	76	82		ignore 4
6	82	88		ignore 7
gap	88	174	86	
7	174	180		ignore 6
...				
13	210	216		ignore 14
gap	216	470	254	
14	470	476		ignore 13
...				
36	602	608		ignore 37
37	608	614	6	(always vacant)
38	614	620		ignore 37
...				
51	692	698		50 only

Channel 37 is a special case, it is reserved nationwide and always be vacant. Additionally, 15.709(c)(4) is more stringent on the emissions limits for operation in channels 36 and 38.

PLMRS/CMRS Metropolitan Areas

Call sign

SBI assumes that a call sign for the PLMRS/CMRS Metropolitan Areas can be left blank.

Low Power Auxiliary Services Protection at PLMRS/CMRS Waiver Sites

SBI assumes that two channels must be reserved for low power auxiliary services at any PLMRS/CMRS waiver site listed in the FCC databases.

Allowable Channels Reserved for Low Power Auxiliary Services

SBI assumes that the two channels reserved for low power auxiliary services in PLMRS/CMRS areas are from the channel range of 21 to 51.

Selection of Channels Reserved for Low Power Auxiliary Services

SBI assumes that it is acceptable to *not* reserve channels for low power auxiliary service if the selection criteria cannot be met. An entry will still be present in the TV bands database, but it will not contain a channel number to be protected.

15.712(f)(2) states that "operation of TVBDs will not be permitted on the first channel on each side of TV channel 37 (608-614 MHz) that is available, i.e., **not occupied by a licensed service, at all locations within the protection range** of the coordinates of each such area as set forth in section 15.712(d) of this part."

It may not be possible to find a channel that is vacant over the entire protected area. For example, in Miami, none of the channels 21-51 are available over the entire 131 km protection radius from the specified center coordinates.

Offshore RadioTelephone Service Protection

SBI assumes that the southern boundaries of the Offshore Radio Telephone protected areas are the Outer Continental Shelf.

Radio Astronomy Site Protection

SBI uses the following coordinates for the Naval Radio Research Observatory in Sugar Grove, West Virginia:

38° 31' 02" N and 79° 16' 42" W (38.517222, -79.278333)

Coordinates are not provided for this site in the FCC rules.

Practical Considerations

The following comments and observations are made based on the experiences of deploying the networks described above. This covers areas where we see practical limitation in the current rules and areas where White Spaces device operation and incumbent protection can be improved.

Antenna Height rules

In rural areas the antenna height rules seem unreasonable and unnecessary. Specifically, the maximum height of the base station antenna is very restrictive. Analysis of our Claudville deployment shows that with a higher antenna height, not only could a significantly greater area be covered but the link budgets (reducing NLOS situations) would have improved the overall data rates. This would have dramatically improved the cost effectiveness of using TV White Spaces for rural broadband applications (less infrastructure) by a factor of 3. In addition the client or spoke nodes did not work with the specific antenna height limits defined in the rules. In most cases the appropriate place to mount the antenna was on the side of a building. In such cases, with a directional antenna pointed back at the base station the effective radiation into the surrounding structures was near zero. In some cases a fence post or local power pole made an ideal mounting point. For aesthetic and practical reasons, the mounting point was typically 2-3 meters above the ground, rather than the minimum required 10 meters.

Maximum Power

In existing deployments increasing the power above 4W would not have made a significant difference in the network, however we did observe the limitations of the power limits and in very rural and remote areas. We could easily see that raising the power above 4W could be significant in making the solution cost effective. While the database could accommodate this and determine the power within any given channel we would also suggest that when there is a 3rdadjacent channel is unoccupied (See figure 6 below) the power could be raised without increasing the risk of interference (20W seems reasonable based on the current spectral mask). Industry Canada has adopted a similar approach in their **SRSP-300.512 - Technical Requirements for Remote Rural Broadband Systems (RRBS) Operating in the Bands 512-608 MHz and 614-698 MHz (TV Channels 21 to 51),** allowing a transmit power of 20 W.

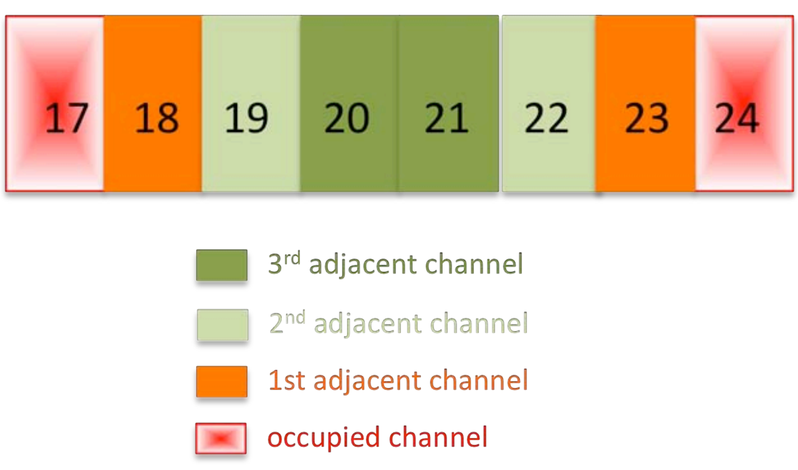

Figure 6: Adjacent channel example

Sensing vs. Database protection

Our position is that sensing is not feasible at this time, as it adds significant costs and reduces reliability. The Database provides for very flexible management of interference – a new and unique concept. We have demonstrated numerous enhancements to the basic Database concept to show how interference can be successfully managed.

Flexible "certificates" the channel map can be enhanced in a number of ways to allow for more efficient and effective use of spectrum, for instance:

Variable time: in remote areas a channel map may be valid for a week, in a congested metro area maybe only for a few hours, significantly increasing the likelihood of avoiding transient or intermittent incumbents.

Revocation: A mechanism by which a channel map can be revoked forcing the device to reregister or shut down

Variable Power: specify the maximum power of a device on individual channels

Once the device is under Database control the ability to modify its operating characteristics can be made in almost real time. This creates a significant enhancement to interference control and management

Examples of Database control to improve interference management, above and beyond those described before. These can be performed on a very granular basis – they do not have to be across the board

Modification of the buffer zone

Limits on maximum power

Changes to the Mask

Usable TV Channels

There has been much debate by the MSTV and others about the impact of TV band devices on TV receivers and wireless microphones. To date we have not observed any such interference related to the radios we have deployed even though several are known to be in close proximity to TV equipment and wireless microphones. This is consistent with the observations made by Microsoft in their Redmond test network[4]. We have however found significant interference from TV Transmitters, both in band and out of band. The strength of the TV Transmitter means that in outdoor installations the TV White Spaces radios are impacted hundreds of miles away from the source. Further we have noted from these installations and installations of 220MHz band telemetry systems that radios within the contour of a TV transmitter will be impacted by out of band emissions in adjacent and non adjacent channels. Figure 7 shows the expected received signal strength for 25 and 50 foot antenna in Lake Mary (http://www.fcc.gov/mb/engineering/maps/). Figure 8 shows the available TV White Space based on the FCC NPRM. This clearly shows that several channels that are theoretical TV White Space have significant in-band emissions from distant TV transmitters. These levels of interference would clearly impact a sensing radio and in many cases are sufficient to preclude operation of CSMA like protocols.

[4] ECFS: 04-186 04-29-2010 Microsoft Corp. 7020443732-2.pdf, Microsoft Ex-Parte submission on presentation of trial network in Redmond WA. to FCC staff on April 28, 2010

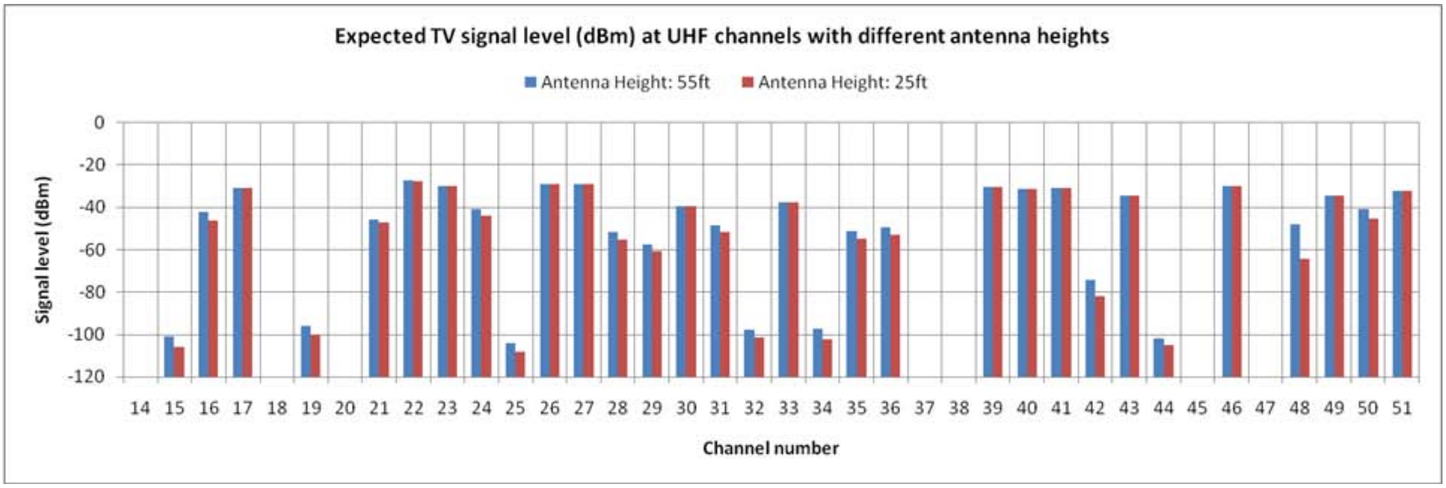

Figure 7: Anticipated interference in Lake Mary from TV stations

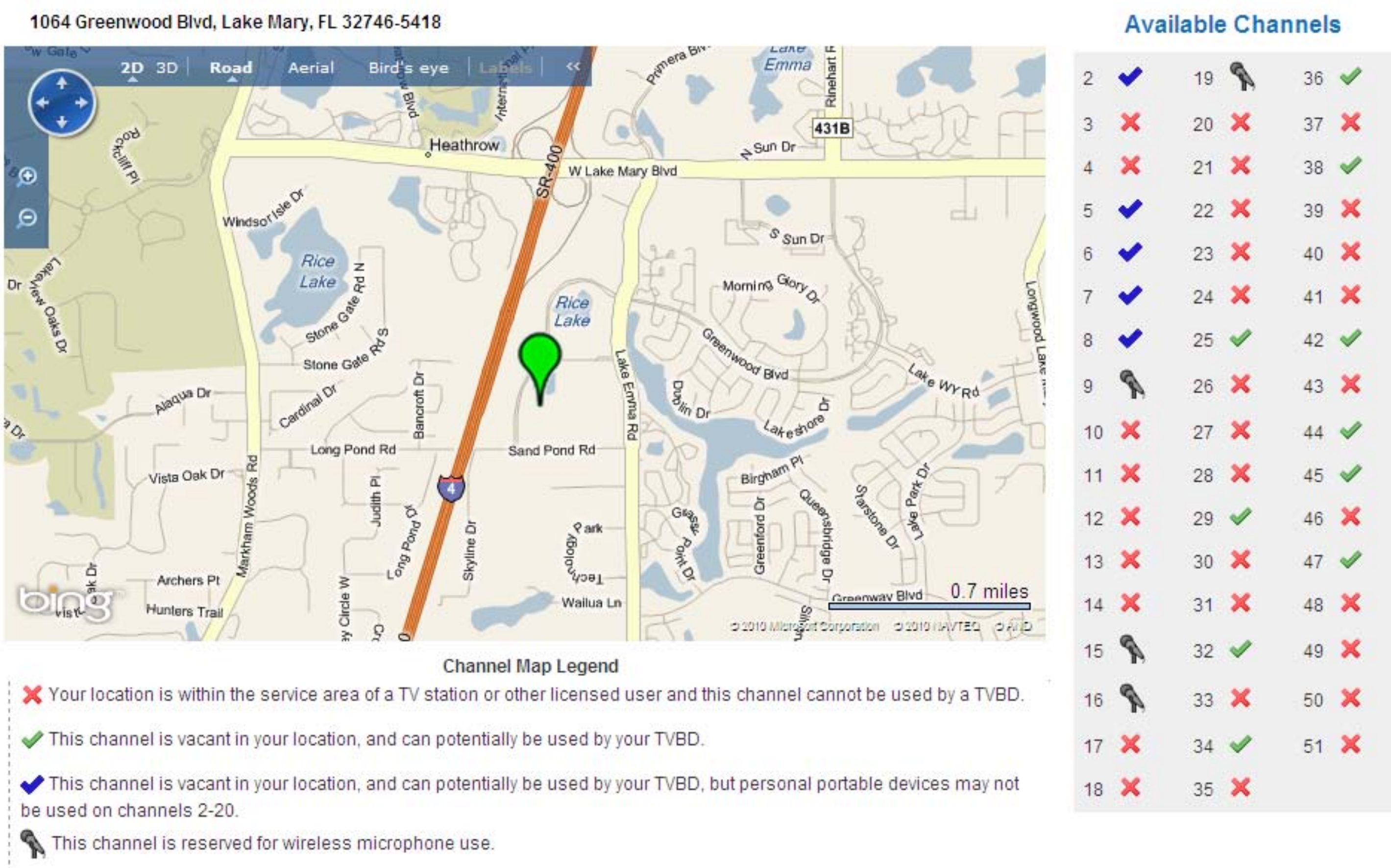

Figure 8: TV White Space available in Lake Mary, according to FCC rules

Lightly Licensing or channel reservation

Several entities have filed comments on the TV White Space proceeding requesting special provisions to support specific business models. More specifically, they have proposed exclusive access to certain channels in rural areas for backhaul use[5] and a light licensing[6] scheme similar to the 3.65GHz rules. Spectrum Bridge has demonstrated and firmly believes that a centralized database is an effective mechanism to allocate, manage and optimize the availability of spectrum. In addition, we reaffirm our position that only minor changes and the removal of a sensing requirement is required to effectively employ white spaces spectrum. The inherent advantage of the database approach is that it can efficiently manage spectrum use, and mitigate interference. In this way, it is entirely feasible to monitor the effectiveness of the proposed approach, and incorporate minor adjustments, via the database, without changing the rules or impacting TVBDs. For example, if a specific cause of interference to an incumbent is identified or a special need for a protected entity arises, the database can be modified to reflect this on a temporary or permanent basis, as SBI has shown the FCC[7]. One item that remains, is to convince incumbents that, implemented effectively, the database becomes an effective means in quickly resolving interference issues, and such situations can be resolved in real time -- a dramatic improvement to the current system. In order to fully exploit the proposed capabilities of the database the incumbents should embrace the database and encourage TVBDs to register and utilize the database. This will greatly enhance the potential to identify and manage any interference issues.

Emission Limits

Out of band emissions limits for various broadband technologies is typically specified at values less than -50 dBr at the band edge. Some specific examples of this are:
OOBE requirements for high power broadband technologies deployed under 47 CFR Part 27 requirements is typically specified as 43 + 10 log (P) dB.
OOBE requirements for unlicensed bands such as 2.4 GHz is dictated by, 47 CFR Part 15.205, and although these requirements are specified in different terms, they dictate very similar performance in terms of relative power.
OOBE requirements for Digital LPTV is specified by 47 CFR Part 74.794 as -46 dBr at the channel edge.

The current requirement for TVBDs is specified in 47 CFR 15.709 and stated as “Undesirable emission limits for TVBDs are as follows: In the 6 MHz channels adjacent to the operating channel, emissions from TVBD devices shall be at least 55 dB below the highest average power in the band.”

Although this requirement was proposed by the White Spaces Coalition (Dell, Google, HP, Intel, Microsoft, Philips) in March 2007, "to make certain that out-of-band interference limits are maintained", experience and measurements have shown that this is not attainable via commercial off the shelf (802.11 or 802.16e) equipment operating in a 5 MHz channel (defined by 802.11j) or (802.16) equipment operating in a 3.5 or 5 MHz channel. This is further documented by Microsoft’s analysis “A Hardware Platform for Utilizing TV Bands With a Wi-Fi Radio”, which discusses the implications and necessary filter requirements needed to achieve compliance.

To quickly capitalize on the advantages and dividends offered by White Space, low-cost, standards based solutions should be employed. Experimental data and practical experience with white space deployments show that a minor relaxation in these requirements is feasible and would bring practical solutions to market more quickly. In addition the database can accommodate such a change by balancing it against a more strict contour or buffer zone.

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[5] ECFS: 04-186 05-18-2010 FiberTower, Sprint Nextel, COMPTEL, and the Rural Telecommunications Group 7020461867.pdf

[6] *Ex Parte* filing by the Wireless Internet Service Providers Association, GN Docket No. 09-51 and ET Docket Nos. 04-186, 02-380 (filed Mar. 5, 2010)

[7] ECFS 04-186 06-04-2009 Spectrum Bridge, Inc. 65200218866.pdf SBI White Spaces Database demonstration to OET